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Natural Resource Stewardship and Science

Garlic Mustard (*Alliaria petiolata*) Monitoring at Effigy Mounds National Monument

Year 2 (2010)

Natural Resource Technical Report NPS/HTLN/NRTR—2012/617

ON THE COVER
Forest in early spring at Effigy Mounds National Monument. NPS file photo.

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Heartland Network
Natural Resource Monitoring

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Executive Summary

Garlic mustard, the invasive plant of most immediate concern at Effigy Mounds National Monument occupied approximately half of the search units within the park. In 2006, we estimated that the plant occupied somewhere between 36 and 70 acres on the park and between 9 and 17 acres in 2011. Control efforts in 2009, however, could not be conclusively linked with this decrease. We also documented four additional invasive plant species in Effigy Mounds National Monument: common buckthorn, Japanese barberry, multiflora rose, and shrub honeysuckle. The relatively low abundance and high management feasibility of these species suggested that control is possible. The timing of the survey to maximize garlic mustard detection, however, likely overlooked a sizeable portion of invasive plant species that can best be detected during the growing season.

Introduction

Invasive plant ecology has received considerable attention in recent years because of the potentially detrimental effects of invasive plants in natural ecosystems. Invasive plants can displace native plant species (Daehler 2003), change fire regimes (Evans et al. 2001), disrupt nutrient cycling (Rodgers et al. 2008), and change ecosystem structure and function (Vitousek et al. 1997). Areas where invasive plants dominate may require costly restoration efforts for which success may be limited or changes impossible to reverse. Several functional traits of plants are associated with invasion potential (Anderson et al. 1996). These attributes usually include high population growth rates, short life-cycles, high reproductive effort, high rate of autogamy, and pollination by generalist pollinators. These characteristics well describe garlic mustard (*Alliaria petiolata* (Bieb.) Cavara & Grande).

Garlic mustard, native to Eurasia, was first introduced to North America around 1868 (Cavers et al. 1979). The plant spread to its current range, extending from New England to the Midwest and from Ontario to Tennessee (Welk et al. 2002). Garlic mustard is a biennial plant that is able to invade undisturbed, mature eastern deciduous forests. Its ability to circumvent the "disturbance pathway" (Hobbs and Huenneke 1992), often required to facilitate the spread of invasive plants, has made the species difficult to control. Examination of the garlic mustard life cycle, however, has allowed land managers to match control techniques to particular life stages.

The garlic mustard life cycle consists of three stages: seedling, rosette, and adult plant. The seedling stage begins after germination, which takes place between February and March (Anderson and Kelley 1995). Seedlings mature as rosettes in early summer and then overwinter (Cavers et al. 1979). Between March and late April of the second year, rosettes bolt, growing at a rate of 1.9 cm per day (Anderson et al. 1996). After bolting, plants flower around May and disperse mature seeds from dehiscent capsules between July and September (Cavers et al. 1979). The plants senesce shortly thereafter between September and October.

Seed Dormancy in Garlic Mustard

Researchers found seed dormancy in garlic mustard to be 8 months for southern populations (Kentucky) and 20 months for northern populations (Ontario) (Nuzzo 2000). No specific information on dormancy, however, is available for the region surrounding Effigy Mounds National Monument, which lies between these northern and southern study sites. In northern Illinois forests, high adult abundance was consistently followed by high seedling abundance the following spring, suggesting 8-month dormancy (Nuzzo 1999). In this report, we interpret data assuming an 8-month seed dormancy period.

Vital Signs Monitoring at Effigy Mounds National Monument

The vital signs monitoring protocol for invasive plants in Effigy Mounds National Monument is timed to estimate plant cover during the late October to early November of every fourth year. The fall timing is selected to focus on garlic mustard abundance. Plant visibility is generally high at this time of year following dieback, dormancy, or leaf fall of most other plants. Surveys at this time center on plants that are likely to flower during the next growing season. Increases or decreases in the abundance of this life-stage are expected to reflect general population trends. Maps produced based on these data, however, may not account for patches consisting solely of adult plants in the months prior to monitoring. As adult plants senesce in late summer, those patches might lack rosettes during the monitoring period, yet are still capable of supporting a single-age cohort of seedlings the following spring (Van Riper et al. 2010). This scenario may result in an underestimation of park-wide plant abundance compared to estimates the following spring.

Natural Variability in Abundance of Garlic Mustard

In contrast to linear and compensatory recruitment functions, the population growth curve of garlic mustard has been described as overcompensatory (Zipkin et al. 2009) (Figure 1). Overcompensatory growth describes growth curves in which juvenile recruitment increases as adult density decreases due to factors such as harvesting and declines as adult abundance increases (Zipkin et al. 2009). In garlic mustard, density increases rapidly after germination and decreases asymptotically due to thinning processes. Garlic mustard seedling density can be as high as 830-1800/m^2 in the spring, while in the following year spring rosette density can drop to as low as 4-102/m^2 (Nuzzo 1993). The reduction is attributed to density-dependent and density-independent effects in the vital rates of garlic mustard.

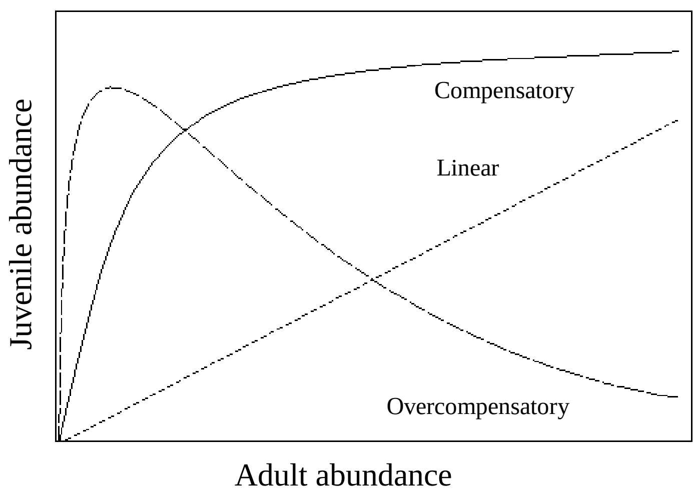

Figure 1: A generalized comparison of potential juvenile responses to harvest of adults in density-dependent populations. These responses may be linear (reductions in adults are directly correlated with juvenile reductions), compensatory (juvenile abundance is only reduced once adult abundance is reduced beyond a threshold), or overcompensatory (juvenile abundance increases to a threshold as adult abundance decreases). Garlic mustard exhibits overcompensatory growth. (from Zipkin et al. 2009)

The following garlic mustard vital rates were observed to be density-dependent: fertility (i.e., number of seeds produced per individual), seedling survivorship to rosette, and rosette survivorship to fall (Pardini et al. 2009). Fertility is a function of population density as low-density satellite populations produce more seeds per plant than dense “core” populations. In addition, intraspecific competition between the various life-stages of garlic mustard affected plant abundance in a given year. This competition is a direct consequence of garlic mustard’s short distance dispersal of 1 to 2 m (Nuzzo 1999, Burls and McClaugherty 2008). Adult density largely influences seedling survivorship as the period of shoot elongation of adults overlaps that of seedling germination. This competition causes high mortality (>50%) for seedlings from a single stand that reach late spring rosettes (Cavers et al. 1979). Even in the absence of adult plants, natural mortality was high for seedlings because of garlic mustard's overcompensatory recruitment function. In addition to plant density, nutrient availability has also been shown to alter the severity of this density-dependent competition (Van Riper et al. 2010). Nutrient poor habitats with reduced adult density allow for the recruitment of more seedlings.

Density-independent variables of germination and rosette survivorship through summer and winter also explain variability in garlic mustard abundance within and between years (Pardini et al. 2009). For example, garlic mustard seeds require 50 to 105 days of cold stratification and freeze-cycles to break dormancy (Nuzzo 2000). Percent germination and abundance in the following spring were linked with these germination requirements. Similarly, abundance of fall rosettes was attributed to the severity of summer droughts as developing rosettes were vulnerable during this period (Nuzzo 2000). In the following winter, the cause of rosette mortality shifted to winter length and severity (Pardini 2009). This reduction of garlic mustard density was evident in a northern Illinois forest where a 78.6% reduction in rosette density from November 1989 ($186.4/m^2$) to May 1990 ($39.9/m^2$) was observed (Nuzzo 1993).

Several studies have quantified garlic mustard mortality, which integrates density-dependent and independent processes, from seed to adult. In Ontario, only 5-9% of seeds produced from a single stand matured to rosettes (Cavers et al. 1979). Of these rosettes, only 2-4% survived to flower. Similarly, Baskin and Baskin (1992) and Nuzzo (1993) reported respectively 1% and 3% of germinated seedlings surviving to reproduction. Despite these high mortality rates, garlic mustard can spread at a rate of 5.4 m/year with satellite populations emerging 6 to 30 m from the population front (Nuzzo 1999). This rate of spread allows garlic mustard density to double in four years and triple in eight years (Nuzzo 2000).

Management-Caused Variability in Abundance of Garlic Mustard

Management actions at Effigy Mounds National Monument also effect garlic mustard abundance. Workers divide their control efforts in to three phases: spring, summer, and fall. Spring treatment involves the application of herbicide to seedlings and second year rosettes during mid-April to early May (Figure 2). Summer treatment consists of staff using propane torches to destroy seed in undehisced siliques. Fall treatment consists of chemical application on first year rosettes prior to their overwintering. These management techniques presumably alter plant abundance through a combination of direct mortality and seed reductions. Therefore, management techniques alter garlic mustard populations in three ways as observed in fall surveys: (1) management altering plant cover during the current year, (2) management altering plant cover during first year post-treatment, and (3) long-term management altering cover over many years.

Management-Caused Changes in Cover During the Current Year

Management actions can reduce cover during the same year as treatment. Herbicide application to seedling and second year rosettes in the spring will only show evidence of control as a reduction in first year rosettes (second year rosettes would not have survived to fall). Similarly, summer burning designed to destroy undehisced siliques may inadvertently reduce seedling cover resulting in reduced rosette cover in the fall. Herbicide treatment during the fall may or may not affect survey results in November depending on whether or not rosettes have ample time to succumb to treatment prior to the survey.

Management-Caused Changes in Cover During the First Year Post Treatment

Inspection of areas treated for garlic mustard one year after treatment can yield different responses in abundance depending on whether treatment occurred pre- or post-dispersal (Figure 2). With pre-dispersal treatments, the seed bank determines abundance the following year (i.e., dormant seeds repopulate the area). Garlic mustard seed viability has been observed to be 3-5 years (Baskin and Baskin 1992), 5 years (Hochstedler and Gorchov 2007) and as much as 10 years (Nuzzo 2000). Germination differs also over time following dispersal. A field simulated germination experiment reported 17.2% and 2.4% germination for the first and second spring, respectively, within a single cohort (Anderson et al. 1996). Another greenhouse experiment showed 19.5-55.4% germination for the first spring, 1.4-24.1% for the second spring, and 0.1-1.5% for the third, fourth, and fifth springs following a single sowing (Roberts and Boddrell 1983). Treatments that reduce seedling and second year rosette cover in the spring eliminate seed dispersal events of two generations. Germination from older cohorts are much lower than first year germination, which might produce rosette cover slightly lower than that expected from first year germination. Fall rosette removal, (i.e., post-dispersal treatment), eliminates the potential dispersal of seed the following year, but neglects to reduce seed dispersal in the management year. When garlic mustard plants are treated only in the fall, cover will likely attain levels similar to those during the previous year.

Long-Term Management Altering Cover Over Many Years

Successful eradication of garlic mustard populations is largely dependent on initial population size, age, and seed bank (size and viability) (Drayton and Primack 1999). The time required to eradicate garlic mustard populations was estimated in an experimental extinction study (Drayton and Primack 1999). The experiment demonstrated that after four years of adult removal prior to seed set, 43%, 9%, and 7% of populations went extinct for populations sizes of 10 or fewer than 10 plant, 11-49 plants ,and 50 or more plants, respectively. Only control populations with 10 or fewer plants went extinct (11% extinction rate). Smaller populations appeared more vulnerable to treatment effects than larger populations, which highlights the importance of early detection and treatment. This study also showed that despite most germination occurring within two years of dispersal (Anderson et al. 1996), some experimental populations where able to increase despite heavy management efforts (Drayton and Primack 1999). Generally, 3-5 years of intensive management is required to completely remove garlic mustard populations (Nuzzo 1991).

Density Increase in Response to Management

Garlic mustard's ability to persist and proliferate even with intensive management reflects its complex stage-structured and density-dependent population dynamics (Pardini et al. 2009). Increased survival and/or fertility rates of the remaining individuals can compensate for management-caused mortality. (Buckley et al. 2001). Based on population models, high mortality rates (>95% for rosettes and >85% for adults) are needed to reduce garlic mustard population densities (Pardini et al. 2009). Management efforts that achieve less than the mortality thresholds for population reduction are not only ineffective, but population densities may increase. This phenomenon is known as "hydra effect", "paradoxical increase", and "overcompensation" (Zipkin et al. 2009). The Greek mythological creature Lernaean Hydra was infamous for her ability to regenerate two heads for every severed one. Species exhibiting this type of population growth characteristically have high fecundity over a short period, short juvenile stages, and constant survivorship rate (Zipkin et al. 2009) – traits that characterize garlic mustard. Removing adults in spring will increase seedling, and, consequently, rosette recruitment the following fall by reducing intraspecific competition with adults plants (Pardini et al. 2009). However, with persistent management, the hydra effect is only a temporary phenomenon since it relies on a seed bank (Zipkin et al. 2009). As ongoing management reduces the seed bank, fewer seeds are left to replace the individuals removed from the population.

Methods

Field Methods

Craig Young and Tyler Cribbs conducted the first survey during October 23-27, 2006. The survey methods followed those outlined in Young et al. (2007). Jordan Bell, Ashley Dunkle, Chad Gross, and Craig Young Staff, all affiliated with the Heartland Inventory & Monitoring Network, conducted the second survey during November 9-11, 2010. The survey was conducted in late fall to maximize detection of garlic mustard. The locations of additional invasive plant species were documented, although other invasive plant species had likely already senesced and were not detectable. The plant species identified during this period with the exception of Chinese lespedeza can be clearly and consistently recognized because of persistent leaves or distinct growth form.

The survey spanned the entire park, although observations were restricted to the areas along line transects (Figure 3). Transects were usually 200-m intervals unless clipped by the park boundary and were oriented in a 45º direction. A total of 272 transects were established. Of these, seven transects were 0 to 50-m in length, 25 were 50 to 100-m in length, fifteen were 100 to 150-m in length, and 225 transects were 150 to 200-m in length. Line transects were loaded as navigation files on GeoXT GPS units. In 2006, 220 transects were surveyed, while 272 transects were surveyed in 2010. None of the transects excluded in 2006 were found to support garlic mustard in 2010. In some cases, however, extremely steep transects were observed from a distance or may have been missed. We will attempt to map these excluded areas more precisely during subsequent surveys.

While using a Trimble GeoXT GPS unit to navigate along transects, surveyors recorded the location of invasive exotic plants. Invasive exotic plants were documented in as wide a belt as possible. The belt width varied based on terrain. In order to provide a finer resolution of cover estimation than required by the protocol (Young et al. 2007) GPS points were collected along the transect to represent approximate locations of plants. Each GPS point represented the location of a group of plants at which the observation was made and did not necessarily represent the exact location of the plants. For each point, the the cover of invasive exotic plants to the nearest 10 m^2.

Analytical Methods

Data analysis involved the production of simple maps (Figures 4-6), as well as a calculation of observed plant cover and frequency for each invasive exotic plant encountered in Effigy Mounds National Monument (Table 1). While we were uncertain of the exact area observed along transects, we calculated park-wide abundance of garlic mustard assuming that at least 5% and as much as 20% of the park area was observed. In order to evaluate changes in garlic mustard abundance, we calculated the difference in abundance between 2006 and 2010 for search units, which had been sampled during both periods (n=220). After buffering each transect with a square which used that transect as a bisecting axis, we intersected this set of squares with polygons identifying treatment locations in 2009 (Figure 7). All transects included in a square that overlapped with the treatment polygon were designated as “treated”. We then conducted a chi-square test to analyze the relationship between transects increasing, decreasing, or static in abundance in garlic mustard abundance with the incidence of chemical treatment.

Invasiveness Ranks

In order to provide additional information on the invasiveness of the invasive exotic plants identified in Effigy Mounds National Monument, the components of the I-rank were listed (Table 1). The I-rank considers the ecological impact, current distribution and abundance, trend in distribution and abundance, and management difficulty of a particular plant (Morse et al. 2004). The ecological impact and management difficulty sub-ranks were also provided as an indicator of the management challenges that the invasive exotic plants posed. I-ranks and sub-ranks are given as high (H), medium (M), low (L), insignificant (I), unknown (U), or a combination of ranks.

Results and Discussion

Garlic mustard (*Alliaria petiolata*), the most abundant invasive plant monitored, was distributed widely throughout the park, although few occurrences were observed in the monument's south unit. A total of 49.6% of transects supported garlic mustard in 2006 and 2010 (Figures 4 and 5). Within transects, we observed a reduction from 7,070 m^2 in 2006 to 3,600 m^2 in 2010 (Figure 6). This amounted to a park-wide estimate of between 36 and 70 acres in 2006 and between 9 and 18 acres in 2010. Decreases were greatest in the park's Heritage Tract. Small increases in cover, however, were also observed across the park.

Of the 220 transects studied in 2006 and 2010, 128 (58%) supported garlic mustard during at least one time period. Of these 128 transects, 53 (41.4%) were classified as increasing, 12 (9.4%) were classified as stable, and 63 (49.2%) were classified as decreasing. Based on the 2009 treatment locations, treatment did not consistently explain categorization of a transect as increasing, decreasing, or stable as 76.2% of treated transects showed decreases compared to 62.2% of untreated transects (chi square = 3.27, p=0.195) (Figure 7). Treatment during two years (2009 and 2010) compared to 1 year or no years of treatment also did not affect categorical changes in abundance (chi square = 6.66, p=0.155). While spatial error in the data may contribute to a non-significant result, the relatively similar percentage of transects increasing and decreasing with and without treatment indicated that factors other than treatment affected change in plant abundance. We recognize that this observation is not definitive given the coarseness of the available data. It is highly encouraging that the garlic mustard population size has decreased, which still holds out the possibility that management has contributed to this decline. A neutral or increasing observation would have been more discouraging and suggested that treatment was ineffective or led to an overcompensatory response in the population.

Despite the differing levels of garlic mustard rosette mortality suggested as required to achieve population reduction (>95% Pardini et al. 2009; >63% Evans and Davis 2010), the qualitative implication is that meeting some mortality threshold is required. To further increase treatment success and efficacy, specific target areas for management should be delineated and treated meticulously and repeatedly before moving on to new unmanaged areas. This action decreases the possibility of newly germinated and untreated plants from repopulating areas treated. Hand pulling of adult plants is also recommended by Pardini (2011) because of the high removal efficacy, though such actions at Effigy Mounds National Monument are impractical. While 3 to 5 years was required to eradicate garlic mustard in experimental plots, the time horizon is likely longer at this scale given that the size of the park makes complete removal each year difficult.

In 2010, a total of four additional invasive exotic plant species were documented in the forest understory (Table 1): common buckthorn (*Rhamnus cathartica*), Japanese barberry (*Berberis thunbergii*), multiflora rose (*Rosa multiflora*), and shrub honeysuckle (*Lonicera* spp). The distribution and abundance of the species varied widely. Japanese barberry, multilflora rose, common buckthorn, and shrub honeysuckle were documented in the forest understory. Shrub honeysuckle was the most widespread invasive shrub with an observed cover of 95 m^2. The other shrubs were observed in eight or fewer transects. *Lespedeza cuneata* was not observed in the 2010 survey.

The I-ranks given for the species showed that four of the five invasive exotic plants observed in the 2010 survey have a high or high/medium I-rank. The management difficulty, however, for all invasive exotic species encountered was characterized as medium or less. Given these ranks and the relatively small size of most of these invasive plant populations, control of these species appears to be feasible.

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Pre-Dispersal Treatment

| Management | Effects |

↓1st year plants (seedlings)
↓2nd year plants (rosettes)
↓Rosettes
*↑Seedlings overcompensate
↓Rosettes
↓Seed Set
**↓Rosettes

Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sept. Oct. Nov.
Year 1 Year 2

Post-Dispersal Treatment

| Management | Effects |

↓Rosettes
*↑Seedlings overcompensate
↓Rosettes
↓Seed Set
↔Rosette

Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sept. Oct. Nov.
Year 1 Year 2

Figure 2. Chart illustrating the effects of treatment timing and life stage targeted on garlic mustard cover as observed the year following management. *Based on overcompensatory growth curve of garlic mustard, an increase in garlic mustard density may be expected after the first treatment. This effect will decrease if management actions reduce the size and viability of the seed bank. **Decrease in abundance expected as product of 2-year old seed bank, but actual cover may vary depending on the magnitude of the overcompensatory growth effect.

Table 1. Overview of invasive exotic plants found on Effigy Mounds National Monument. I-Ranks and management difficulty sub-ranks are given as high (H), medium (M), low (L), insignificant (I), unknown (U), or a range of ranks (indicated by multiple letters) (see Morse et al. 2004).

Scientific Name	Common Name	2006 Plant Cover (m^2)	2010 Plant Cover (m^2)	I-Rank	Ecological impact	Management difficulty
Berberis thunbergii	Japanese barberry	150	70	HM	HM	I
Lespedeza cuneata	Sericea lespedeza	10	0	M	M	ML
**Lonicera spp*	Bush honeysuckle	390	240	H/HM	HM	M
Rhamnus cathartica	Common buckthorn	20	70	HM	M	M
Rosa multiflora	Multifora rose	100	130	ML	L	L
Alliaria petiolata	Garlic mustard	7,070	3,600	HM	ML	M

[*] Species assumed to be *Lonicera maackii* or *Lonicera morrowii*

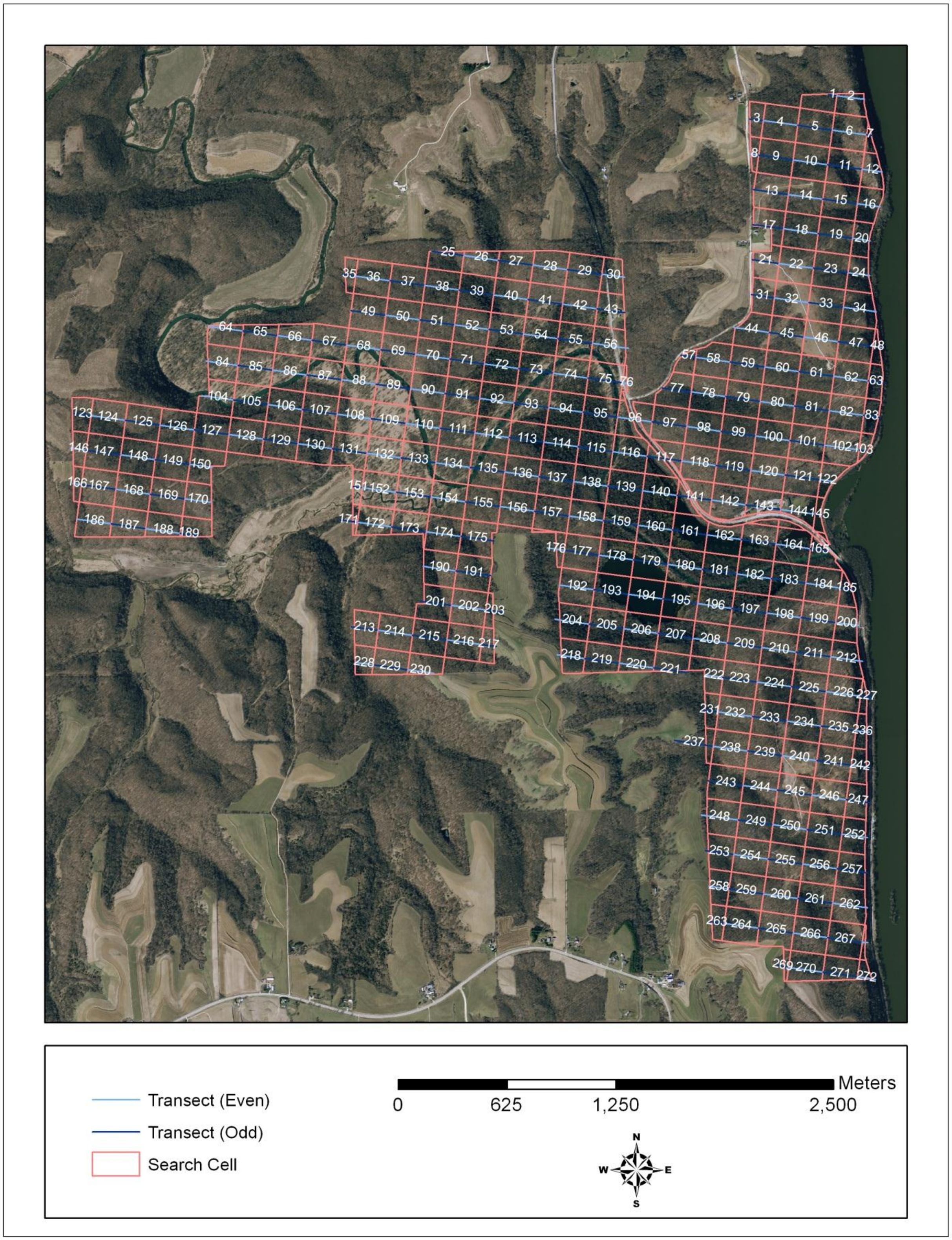

Figure 3. Transects oriented at a 45^{o} angle and followed during invasive plant surveys at Effigy Mounds National Monument. The squares surrounding the transects were used for presentation of changes in abundance and for analysis of the effects of chemical treatment aimed at controlling garlic mustard (*Alliaria petiolata*).

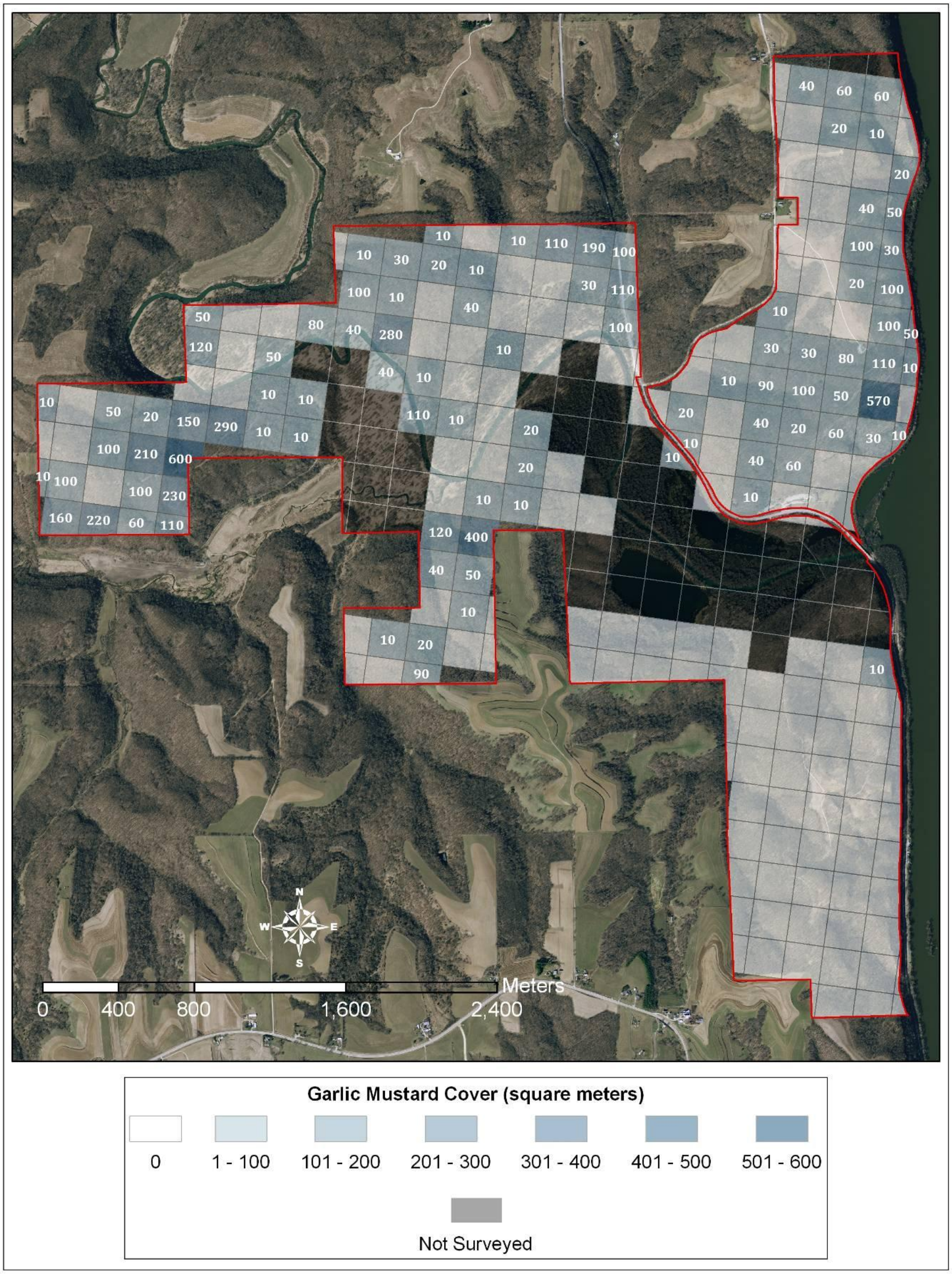

Figure 4. Garlic mustard (*Alliaria petiolata*) cover (m^2) in Effigy Mounds National Monument based on a survey in 2006. Darkened squares indicate areas that were not surveyed. White squares indicate surveyed squares where garlic mustard was not found. Cover values are based on observations along a 200-m transect that bisects each square. Squares were not searched exhaustively.

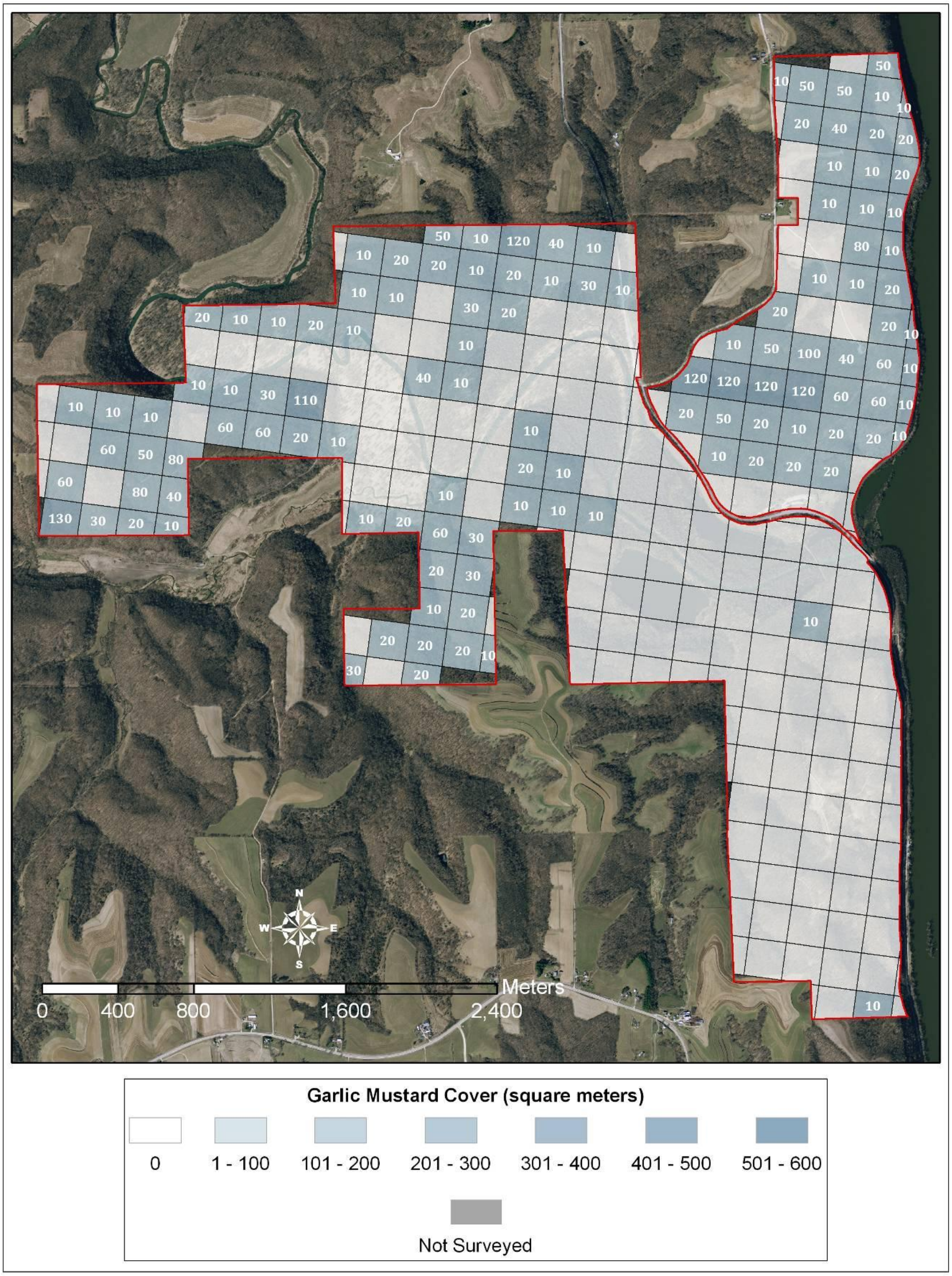

Figure 5. Garlic mustard (*Alliaria petiolata*) cover (m^2) in Effigy Mounds National Monument based on a survey in 2010. White squares indicate surveyed squares where garlic mustard was not found. Cover values are based on observations along a 200-m transect that bisects each square. Squares were not searched exhaustively.

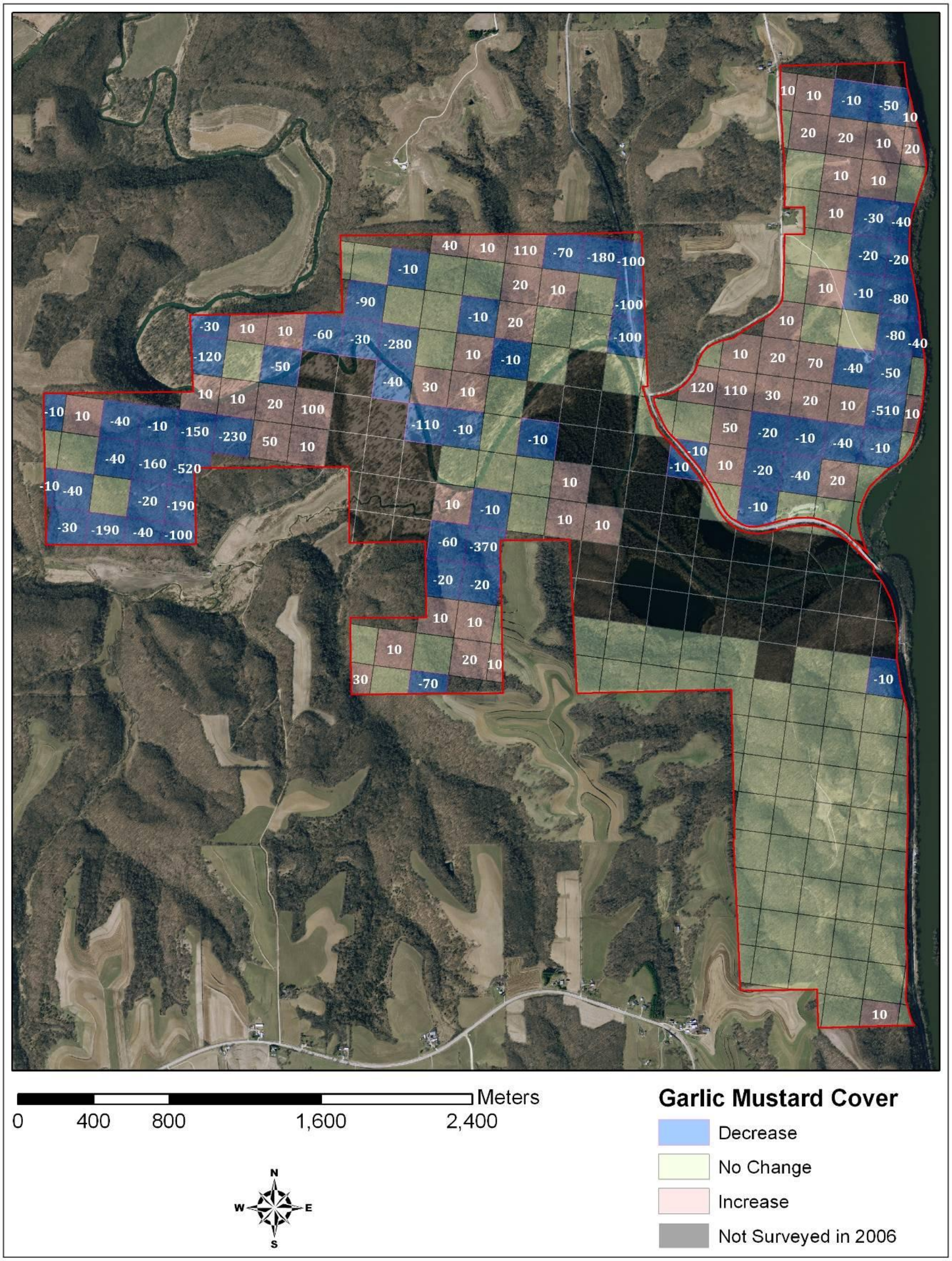

Figure 6. Differences in garlic mustard (*Alliaria petiolata*) cover (m^2) in Effigy Mounds National Monument based on comparison of surveys conducted in 2006 and 2010. Darkened squares indicate squares that were not surveyed. Cover values were based on observations along a 200-m transect that bisected each square. Squares were not searched exhaustively.

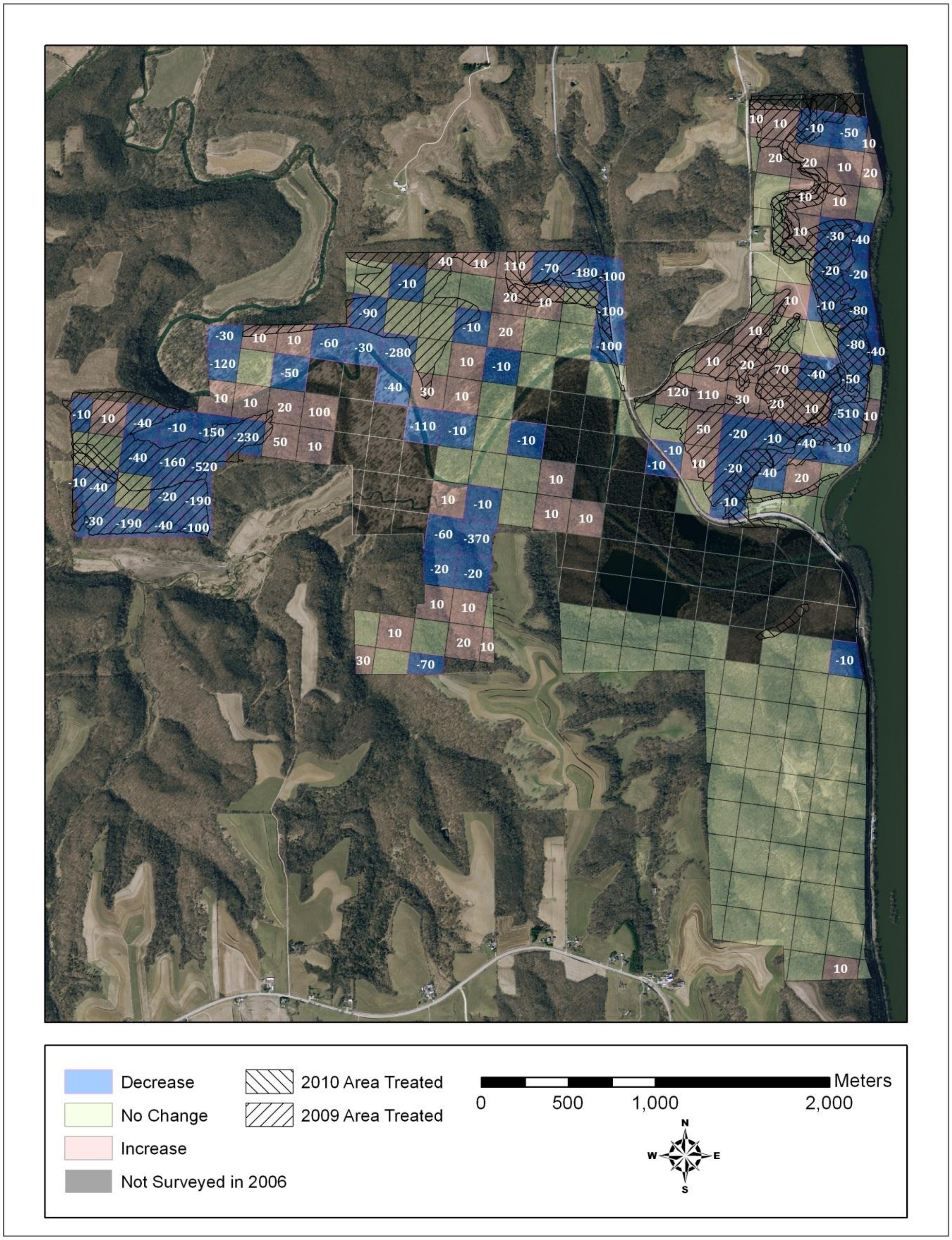

Figure 7. Differences in garlic mustard (*Alliaria petiolata*) cover (m^2) in Effigy Mounds National Monument based on comparison of surveys conducted in 2006 and 2010 and areas treated with glyphosate herbicide in 2009 and 2010. Darkened squares indicate squares that were not surveyed. Cover values were based on observations along a 200-m transect that bisected each square. Squares were not searched exhaustively.

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